VII.I Fuel Cell Characterization

VII.I.1 Neutron Imaging Study of the Water Transport Mechanism in a Working Fuel Cell

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Projected End Date: Project continuation and direction determined annually by DOE

Objectives

- Provide research and testing infrastructure to enable the fuel cell/hydrogen storage industry to test commercial grade fuel cell flow field designs
- Train industry to enable them to use the imaging facility independently
- Transfer data interpretation and analysis algorithms techniques to industry to enable them to use research information more effectively and independently

Technical Barriers:

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- A. Durability
- D. Air, Thermal and Water Management

Approach

- Develop high resolution neutron imaging capability/facility for *in-situ* non-destructive study of water/hydrogen transport in polymer electrolyte membrane fuel cells (PEMFCs) while in operation and hydrogen transport/distribution in hydrogen storage media
- Develop capability for accurate data interpretation and quantitative image processing
- Develop/provide infrastructure/facility for testing fuel cells
- Test fuel cells with partnership with industries and academia; evaluate impacts of research
- Transfer technology to industry as it matures
- Get feed back from users and seek opportunities for future technical breakthroughs

Accomplishments

- Developed capability to study dynamic water transport in real time
- Obtained polarization curve relating output current and voltage to water content

- Developed 3-D imaging of fuel cells
- Developed diagnostic methods to study porosity of gas diffusion layer (GDL) materials

Future Directions

- Install new facility
- Implement fast 3-dimensional imaging techniques to study fuel cells
- Acquire new high resolution detectors with 25 micron spatial resolution
- Study the neutron implementation of coded source methods for faster and sharper neutron image acquisition

Introduction

Neutron imaging is the only *in situ* method for visualizing the water distribution in a "real world" PEMFC. Unlike x-rays, whose interaction with material increases with the number density of electrons, neutrons interact via the nuclear force, which varies somewhat randomly across the periodic table, and is isotopically sensitive. For instance, a neutron's interaction with hydrogen is approximately 100 times greater than that with aluminum, and 10 times greater than that with deuterium. It is this sensitivity to hydrogen (and insensitivity to many other materials) that is exploited in neutron imaging studies of water transport in operating fuel cells.

At the National Institute of Standards and Technology (NIST), we maintain the premier fuel cell neutron imaging facility in the world and continually seek to improve its capabilities. At this facility, imaging the water dynamics of a PEMFC in real time (1-30 Hz) with a spatial resolution of 0.127-0.256 mm is routine. From these images, with freely available NIST developed image analysis routines, PEMFC industry and researchers can obtain *in situ, non-destructive* quantitative measurements of the water content of an operating PEMFC.

Approach

The typical length scales of interest in a PEMFC are: the channels are approximately 1 mm wide and 1 mm deep, the GDL is 0.1 - 0.3 mm thick, the membrane is 0.01-0.05 mm thick, and the active area is 50-100 cm^2. Thus, to study *in-situ*, non-destructive water/hydrogen transport in PEM fuel cells while in operation and hydrogen transport/ distribution in hydrogen storage media we will develop new facilities and improve existing capability for obtaining high spatial and temporal resolution neutron imaging. Employing the mathematical models of neutron scattering, we will develop a software suite that enables users to obtain quantitative measurements of the water content in an operating PEMFC. Due to the complexity of PEMFC and the large number of open questions regarding water transport in PEMFC, we will develop partnerships with industries and academia to train them in the use of the facility, collaborate with them on research projects, and seek their feedback to pursue future technical breakthroughs.

Results

An important parameter determining the water transport in PEMFC is the permeability of the GDL. We are involved with two approaches to measure the GDL permeability. The first infers the relative permeability from model calculations that use as input the measured water volume, current density, and pressure differentials. An interdigitated cell was used in this study to simplify the model equations. The water volume in the GDL was measured with neutron imaging; a standard fuel cell controller measured the other parameters. By varying the current density, the relative permeability as a function of GDL saturation could be obtained, and is shown in Figure 1. This work has been submitted to the *International Journal of Heat and Mass Transfer* for publication. A complimentary method of measuring the permeability of the GDL is to directly measure the water uptake in the GDL through tomography. This tomography work is being developed in collaboration with researchers from Kansas State University and is still in progress.

We have met our FY 2005 milestone of improving time resolution to 30 Hz (about 0.033 s) to provide near real time imaging capability for large samples by installing a large area, fast, flat panel,

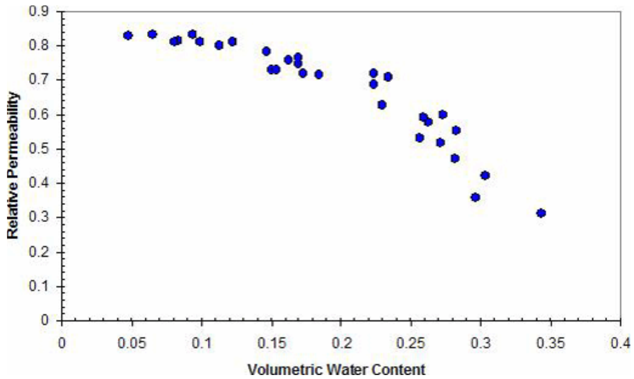

Figure 1. Relative Permeability of the GDL as a Function of Cathode Land Water Content

amorphous silicon detector. This detector can image fuel cells up to 8 inches by 10 inches in cross-sectional area. Software development for user operation of the detector is complete and the detector is in routine use by industry/researchers. An example of the data users can obtain with this detector is shown in Figure 2, which is the change in total water content in 1 s intervals during a transition from open circuit voltage to 1.5 A cm^{-2} over a period of 15 minutes.

We have created a suite of image analysis routines that facility users can use. These analysis routines allow a user to obtain quantitative water volumes in a series of raw images, such as the water volume plot shown in Figure 2a. In addition, the routines can be used to create presentation quality colored images, such as Figures 2b and 2c.

We are currently pursuing several innovative instrument development projects, which will influence PEMFC visualization. One project is “high speed” tomography (3-D imaging). Using the flat panel detector, we have demonstrated that a 3-D image, with a voxel size of $(0.127)^3$ mm^3 of a small (active area 15 cm^2) PEMFC can be acquired in 1-10 minutes, as opposed to 3-6 hours with a conventional charge coupled device camera. A perspective view of the reconstructed image is shown in Figure 3. A second project is collaborating with neutron detector researchers to develop an efficient (up to 80% detection of thermal neutrons), fast (data rate about 10 MHz) neutron detector with high spatial resolution (0.01-0.02 mm). A third project is coded source imaging, which employs a mask of small diameter (about 0.1 mm) pinholes. Coded source

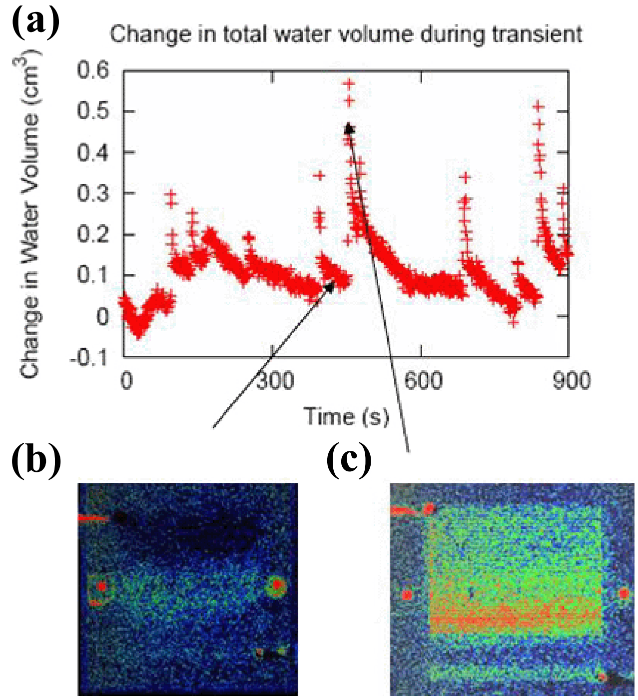

Figure 2. **(a)** The change in total water volume of a 50 cm^2 cell during a transition from open circuit voltage to 1.5 A cm^{-2}. (**b, c**) The two images are false colored images of the water density (red is high volume, blue is low volume) 40 s before the spike, and at the peak of the spike. These data will be compared with model calculations being performed with collaborators at Sandia National Laboratory. (Nathan P. Siegel, Solar Technologies Department and Michael A. Hickner, Chemical and Bio Technologies Department).

imaging might enable obtaining 3-D images from a single 2-D projection, as well as reduce the exposure time for neutron phase imaging. We have successfully performed proof of principle coded source experiments and are actively developing the technique.

Summary

- To encourage open research, we have expanded our user base via increased academic institution participation.
- We are developing cutting edge technology such as improving image spatial resolution to 25 micrometers or better to meet future needs.
- We are developing a new facility to meet the need of a rapidly growing user base.

- We are providing and will continue to provide powerful, a one of a kind diagnostic tool that is helping U.S. industry to solve real world problems in fuel cell research.

FY 2005 Publications/Presentations

1. R. Satija, D.L. Jacobson, M. Arif, S.A. Werner, "In-Situ Neutron Imaging Technique for Evaluation of Water Management Systems in Operating PEM Fuel Cells", Journal of Power Sources 129 (2004) pp. 238–245.
2. D.S. Hussey, D.L. Jacobson, M. Arif, P.R. Huffman, R.E. Williams, J.C. Cook, "New Neutron Imaging Facility at the NIST", Nuclear Instruments and Methods A, 542 (2005) pp. 9-15.
3. T. Trabold, J. Owejan, D. Jacobson, M. Arif and P. Huffman, "In-Situ Investigation of Water Transport in an Operating PEM Fuel Cell Using Neutron Radiography: Part 1 - Experimental Method and Serpentine Flow Field Results", (submitted International Journal of Heat and Mass Transfer).
4. J. Owejan, T. Trabold, D. Jacobson, D. Baker, D. S. Hussey, M. Arif, "In-Situ Investigation of Water Transport in an Operating PEM Fuel Cell Using Neutron Radiography: Part 2 - Transient Water Accumulation in an Interdigitated Cathode Flow Field", (submitted International Journal of Heat and Mass Transfer).

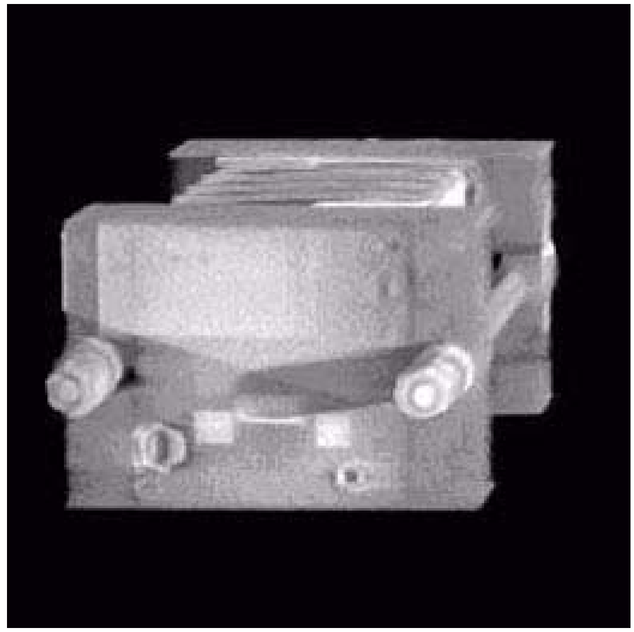

Figure 3. A perspective view of a 15 cm^2 fuel cell created from a neutron tomogram. The 720 angular projections were taken in about 10 minutes and then reconstructed using the filtered back projection algorithm to form the image.